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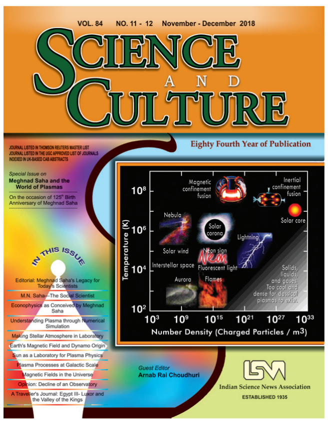
EDITORIAL

MEGHNAD SAHA'S LEGACY FOR TODAY'S SCIENTISTS



Meghnad Saha was one of the founders of *Science and Culture*. More than 125 articles from his pen appeared in the pages of *Science and Culture*, and were later included in *Collected Works of Meghnad Saha* edited by Sanitmay Chatterjee in four volumes. These articles span amazingly diverse subjects such as popular science, river management, national planning, calendar reform, organizing scientific research, etc. Clearly *Science and Culture* was something very close to Saha's heart.

It is only appropriate that *Science and Culture* should celebrate Meghnad Saha's 125th anniversary in a fitting way. When Prof. Suprakash Roy, Editor-in-Chief, requested me to be the guest editor for this special issue in memory of Saha, I felt greatly honoured but was also worried whether I am qualified for this job. We first had to decide what this special issue should contain. One possibility was to invite papers on Saha's life and works. On the occasion of Saha's 60th birthday (barely a year before his death), S.N. Sen, the doyen of history of science in India, edited the volume *Professor Meghnad Saha: His Life, Work and Philosophy*. Again, at the time of Saha's centenary, Saha Institute of Nuclear Physics brought out *Meghnad Saha Centenary Commemoration Volume* (edited by S.B. Karmohapatro) having papers on Saha's scientific work and reminiscences by persons who knew Saha. We decided that we should not try to replicate these past efforts. We felt that the most appropriate way of paying our homage to Meghnad Saha would be to put together a collection of papers which show how he remains relevant today more than six decades after his death.

Most youngsters aspiring for a career in physics research would be learning the basic research tools under the guidance of a supervisor at the age of 26. It was at this tender age of 26 that Meghnad Saha, working at Calcutta University far away from the world's major centres of physics research without a research supervisor, formulated the celebrated thermal ionization theory and revolutionized astrophysics. He established the method of quantitatively calculating the level of ionization in a gas at a certain temperature and density. The theory of thermal ionization was developed in a series of four path-breaking papers published in international journals during 1920-21. In the very first one of these papers, titled 'Ionisation in the Solar Chromosphere' (1920, *Phil. Mag.* **40**, 472), Saha applied his theory to show that the solar atmosphere should be

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ionized and should exist in the plasma state. The last of his four great papers, titled 'On a Physical Theory of Stellar Spectra' (1921, *Proc. Roy. Soc*. **A99**, 135), brought his studies to a glorious finale by showing that the theory of thermal ionization provided an elegant explanation of the classification of stellar spectra developed by Harvard astronomers.

It is often stated that more than 99% of ordinary matter in the Universe is in the plasma state. We now know of various astrophysical constraints which dictate that the ordinary matter made up of electrons and atomic nuclei may not constitute more than 5% of the mass-energy density of the Universe. A higher density of ordinary matter would have made nuclear reactions in the early Universe after the Big Bang too vigorous and the small amount of deuterium that we see today would have been completely destroyed. The Universe seems to have a much greater amount of dark matter (about 25%) which produces a strong gravitational field, but has so far completely eluded all detection methods of observational astronomy. We do not know what this dark matter is made of. Additionally, the accelerated expansion of the Universe suggests that the primary component of the Universe is a kind of mysterious dark energy (about 70%). Although the ordinary matter may be a small component of the Universe, it is only this ordinary matter that emits electromagnetic radiation in different wavelengths and most of our knowledge about the Universe come from this radiation emitted by ordinary matter. If 99% of this ordinary matter is in the plasma state, we need to understand the plasma state to figure out how the Universe works.

Plasma astrophysics, which arose out of Saha's pioneering studies, has emerged as a major area of current astrophysical research. The Earth's surface is a rather unusual place in the Universe where the plasma state is not the most naturally occurring state of matter. But physicists can create the plasma state in their laboratories and study its properties. Apart from the fact that such studies help us to understand the functioning of the Plasma Universe, there is a very important practical goal. If, in a laboratory system, we can replicate in a controlled way the thermonuclear reactions taking place inside stars, then we shall be able to solve mankind's energy problem virtually for eternity. India is now an important partner in the international venture to realize this: International Thermonuclear Experimental Reactor (ITER).

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To show where Saha's own country stands now in the research fields which arose out of his pioneering studies, we present six papers dealing with plasmas from the terrestrial environment to plasmas in the largest astrophysical systems. The authors of these papers, who span roughly two academic generations, are the leading Indian scientists in their respective research fields. The editorial advice to them had been to give an overall introduction to their research fields and also to describe the Indian efforts set in the proper international context. A reader of these papers dealing with plasmas in the earth and in the heavens will form a good idea of where this subject stands now and will also know of the Indian efforts in these studies.

As in many other areas of physics, numerical simulation has emerged as a very important research tool in plasma physics, almost rivalling experimental studies in importance. Amita Das gives a lucid introduction to various methods of numerical simulation for studying the complex behaviour of plasmas. Then Ravindra Kumar discusses various fascinating laboratory experiments – some done in his own laboratory at TIFR – which throw light on plasma processes in astrophysical systems. It may be noted that Saha himself was the first person to carry on plasma experiments in India when he designed an experiment at Allahabad University to study thermal ionization. After the two papers by Das and Kumar focusing on the study of plasmas at the laboratory scale, we begin our journey towards larger systems. Before we leave the terrestrial environment altogether, we can learn from Binod Sreenivasan's paper how the magnetic field of the Earth is generated by a plasma process – the dynamo process – taking place in the Earth's molten metallic core. As we move towards the astrophysical Universe, our first stop is the Sun (Saha's first paper on thermal ionization dealt with the solar atmosphere). Arnab Rai Choudhuri argues that the Sun provides us a unique laboratory for studying various plasma processes. Then Prateek Sharma takes us on a journey to look at plasma processes at the scales of galaxies and clusters of galaxies. At last, Kandaswamy Subramanian confronts some questions at the frontier of dynamo theory research which need to be addressed if we want to understand why the Universe appears magnetized at widely different scales. To the best of our knowledge, this is the first time that papers by these leading Indian scientists (who are also international leaders in their respective fields) are appearing between two covers of a single volume.

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After this survey of the six papers dealing with plasma physics and plasma astrophysics, we come to the first two papers appearing in this special issue. As a perusal of Saha's articles published in the pages of *Science and Culture* would show, he had a deep and abiding interest in various aspects of what we now call social sciences – economics, political science, history, archeology. Vasant Natarajan looks at Saha as a social scientist. Then Bikas Chakrabarti shows how certain discussions on income distribution (while introducing statistical physics) in Saha and Srivastava's famous textbook *A Treatise on Heat* foreshadowed the newly emerging science of econophysics. It may be worthwhile to note that the term 'econophysics' was coined by Eugene Stanley in 1995 during a conference at Kolkata – the city where Saha did his most famous scientific work and where he again spent the last few years of his short active life. These two papers, along with the six papers on plasma physics and plasma astrophysics, will go a long way in showing how Meghnad Saha remains relevant today and will remain relevant for years to come.

We would like to point out that we started making preparations for this special issue barely a year after the passing away of the doyen of plasma physics in modern India: Predhiman Krishan Kaw (on 18 June 2017). He was always tremendously supportive of younger plasma physicists of India. Two of the authors (Amita Das and Ravindra Kumar) had collaborated actively with him. Several of the other authors who might not have worked with him received encouragement from him in many ways. I personally fondly recall that Kaw attended four pedagogical lectures on plasma astrophysics given by me at a winter school in Gandhinagar for graduate students, against my protests that he would be wasting his valuable time by attending these elementary lectures. We take this opportunity of paying our tribute to the memory of Predhiman Kaw. ❐

Arnab Rai Choudhuri
Guest Editor

Prof. Arnab Rai Choudhuri is a Professor of Physics at Indian Institute of Science, Bangalore. Since obtaining his PhD from the University of Chicago in 1985, he has been working on different aspects of theoretical plasma astrophysics. He was one of the originators of the flux transport dynamo model, the currently favoured theoretical model of the 11-year sunspot cycle. His two books *The Physics of Fluids and Plasmas* (1998) and *Astrophysics for Physicists* (2010) - both published by Cambridge University Press - are used as standard textbooks in many universities around the world. He is an elected Fellow of all the three science academies of India as well as The World Academy of Sciences (TWAS).

This photograph shows Arnab Rai Choudhuri standing next to the furnace used by Meghnad Saha in his experiments on thermal ionization and still kept in the basement laboratory of the Physics Department, Allahabad University. This furnace was used in the first plasma physics experiments ever done in India.

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